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Classroom response system-mediated science learning with English language learners

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We report on a case study examining the effects of a technology adaptation on patterns of discourse in a sheltered English high school science unit on electricity. The focus here is on how the tool, a classroom response system (CRS), affected access to and participation in classroom discourse with regard to developing science literacy among English language learners (ELLs), in particular Spanish speakers. Results indicate that, with appropriate pedagogies, CRS integration can provide learners with additional opportunities to become active participants and agents in their own learning by supporting teachers in reshaping their discourse patterns. We highlight how the CRS led to greater engagement by supporting a shift in the rhythm and participation structures of discourse. Implications for use in classroom settings by teachers with a range of expertise in instructional technology are provided.

Keywords: classroom discourse; ELL; language minority students; teacher–student interaction; classroom methodology; teacher talk

Background

Public policymakers emphasize the need for increasing mathematics and science knowledge as international comparisons indicate that US students lag behind students in other countries (National Center for Education Statistics 2000). Such reports further indicate that minority students, among them English language learners (ELLs), are least likely to achieve the expected levels. The Office of English Language Acquisition, Language Enhancement, and Academic Achievement for Limited English Proficient Students reports an increase in this population in the decade from 1994 to 2004 (National Clearinghouse for English Language Acquisition and Language Instruction Educational Programs 2004). With increasing numbers of ELLs, improving science instruction for all learners has become a priority.

The National Science Teacher Association (NSTA) summary of goals and processes of science education emphasizes *discourse* as a key concept in science education. O'Connor (1998) describes the importance of discourse practices within the context of mathematics education:

> . . . if we consider a discourse practice as constituting the underpinnings of a developing mathematical behavior, then access to that practice, or beliefs about it, or culturally conventional restrictions on its use will have consequences for the student's progress in mathematical thinking and communication – consequences that determine which students feel entitled and inclined to engage in discourse practices in reform-minded mathematics classrooms. (33)

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Scholars such as Lemke (1990) and Mortimer and Scott (2003) further focus on the language of science – defining successful science teaching as constituted in discourse practices that guide students to construct thematic arguments and 'talk like scientists' rather than reproducing mechanical recitation of ready-made scientific knowledge.

Classrooms that align with the goals of sociocultural learning theories are characterized by Mortimer and Scott (2003) as those where 'students are able to articulate their ideas, presenting different points of view' (2) supported by teachers who scaffold and support student discourse. They contrast this ideal condition with classrooms in which 'the teacher asks lots of leading questions and the responses from the students tend to be limited to odd words here and there' (2). Mortimer and Scott provide a framework for 'a comprehensive, and fully integrated, set of theoretical tools for analyzing and characterizing the various ways in which the teacher acts to orchestrate the talk of science lessons in order to support student learning' (6). In essence, their framework aims to analyze discourse from the perspective of how effectively it supports students in becoming proficient in 'telling the science story', and they offer their framework 'as a model to refer to *a priori* in thinking about the planning and development of science teaching' (25).

Mortimer and Scott (2003) outline an ideal cycle of teaching that rests on six teaching purposes and a matrix of discourse patterns, which serve to introduce students to new concepts, allow them to grapple with those ideas in their own words and then – with guidance from the teacher – come to a shared understanding of the ideas in the conventional language of science. Classroom discourse patterns outlined along two dimensions that can be linked to the notion of ownership of the science story support the teaching purposes. The first dimension, interactive/noninteractive, refers to the extent to which students participate with the teacher in discussions; the second, dialogic/authoritative, refers to the extent to which different views/theories about the same concept are viewed as worthy of consideration.

In the teaching cycle, they suggest that particular discourse patterns are linked to particular teaching purposes and marked by particular types of turn-taking strategies. For example, the teaching purpose of 'working on ideas', in which students are grappling with new concepts, is ideally accomplished through an interactive/dialogic approach in which ideas offered by students are given equal space for consideration. This type of classroom interaction does not follow the traditional initiation–response–evaluation (IRE) pattern of communication in which the teacher's role is to evaluate students' responses.[1] Rather, interactive and dialogic discourse often takes an initiation–response–feedback–response–feedback (IRFRF) form that allows for joint building and reflection on ideas, with teachers guiding rather than evaluating student responses.

Shifting to a classroom style, i.e. both interactive as well as dialogic, presents challenges when considering classrooms with ELLs, for whom participating in the classroom involves the development of vocabulary and discourse patterns in English appropriate to the science content under consideration. As Lee and Luykx (2007) point out, there is an inextricable link between language knowledge and content knowledge for ELLs:

> In the current US policy context, which stresses 'structured English immersion' for English language learners (or ELL students) and severely limits content area instruction in languages other than English, English proficiency becomes a *de facto* prerequisite for science learning. In this sense, acquisition of oral and written English, although not a 'science outcome' *per se*, plays a large role in determining science outcomes as they are commonly measured. (174)

Langman and Bayley (2007), in a case study of a secondary school science teacher, find that the English as a Second Language (ESL)-trained teacher had insufficient awareness of what 'focusing on discourse' in the classroom means in practice; as a result her intended

goal of creating an interactive classroom that encouraged ELLs to speak fell short. In an attempt to make participation possible, she focused on IRE interaction that required 'yes/no' responses rather than explanations from students.

Haneda and Wells (2008) outline how 'an inquiry approach creates abundant opportunities for EAL[2] students (and native English-speaking students) to engage in the learning of the subject matter through dialogic interaction' (131). Here dialogic inquiry is defined as participation of more than one speaker (as opposed to teacher monologues), corresponding to Mortimer and Scott's (2003) interactive dimension in all cases, and in ideal cases with a dialogic (as opposed to authoritative) communicative approach. They, however, report that instances of such interaction are rare, and tend to be found only when teachers are involved in sustained action research with researchers. Mortimer and Scott (2003) echo this finding, remarking that many classrooms continue to operate as sites for rote memorization and repetition rather than sites in which transformative learning occurs.

A key challenge is *how* to develop discourse patterns that draw learners into the co-construction of knowledge. Research on the potential of technology to support better science instruction for all learners suggests that, when combined with appropriate pedagogies, such technologies can provide additional opportunities for learning and can make the learning experience more relevant, challenging, integrative and exploratory (Guerrero, Walker, and Dugdale 2004; Nicol and Boyle 2003). One relatively simple technology is a Classroom Response System (CRS), essentially an electronic voting technology (Burnstein and Lederman 2001, 2003) that provides instant aggregated feedback to teachers and learners. Such tools consist of (1) transmitters, not unlike TV remote controls that participants use to submit their input, (2) a receiver that collects all inputs and sends them to the (3) central processing unit (the computer), which then aggregates these inputs and creates a graphical output, such as a histogram, that can be projected onto a screen visible to all. With the projection of an aggregate of answers, the CRS provides learners with an overview of how all learners in a class responded to a given question and where their choice fits in the aggregate. This shared view can provide a platform for discussion of the relative merit of different answer options, thus allowing for a deeper understanding of a science concept under consideration, as well as wider participation by students. In other words, such a tool may create a platform for interactive and perhaps dialogic inquiry.

Although general investigations of CRS abound (Fies and Marshall 2006), little research exists on the ways in which this technology may support a teacher in creating a discourse-rich environment for ELLs. Indeed, Lee and Luykx (2007) suggest that the role of technology in science education has yet to focus on the particular ways in which it may support ELLs. This paper seeks to contribute towards building a knowledge base addressing how technology may support science teachers working with ELLs in shifting their discourse to more interactive and dialogic patterns.

We present a case study on the effect of a CRS intervention on a science teacher's discourse style during the first week of use of the tool. Specifically, we examine how CRS use impacted participation by intermediate ELLs in a sheltered English high school science classroom. We demonstrate how the CRS served to mediate the teachers' discursive style by affecting his pacing and by redistributing the burden of talk and thus sense-making from the teacher to the students. Based on data drawn from a unit on electricity, we address the following questions:

(1) How does the introduction of a CRS affect *access to and participation in* classroom discourse?

(2) How does the introduction of a CRS affect the nature of meaning-making in the classroom?
(3) What does an analysis of discourse tell us about how science teaching and learning is instantiated by teachers and students in this sheltered classroom?

Participants, setting and intervention

The study took place in an intermediate-level sheltered English science classroom in a large urban high school in the United States Southwest. Sheltered English is an instructional approach designed to make academic instruction in English accessible to ELLs. The term 'sheltered' refers to the fact that: (1) ELLs do not compete academically with native English speakers since the class is comprised entirely of ELLs; and (2) teachers, ideally trained in ESL, employ a range of adaptations including visual aids, hands-on activities and a focus on vocabulary tied to concept development in content areas.

Mr Green,[3] an experienced science teacher with ESL training, was an energetic and dedicated monolingual English educator who believed in the power of classroom demonstrations and direct experience, as well as the use of ESL-adapted science materials to support learning. A Farsi-speaking college student volunteer, Ms Blue, helped two Farsi-speaking students with translations of the science content, and offered one-on-one help to other students as needed.

Twelve students were enrolled in the course and attended fairly regularly during the study period. Half of these students spoke Spanish as a first language; the other half came from a variety of linguistic and cultural backgrounds and spoke Farsi, Korean, Kirundi, Punjabi and/or Hindi.

The intervention

To allow for a comparison of Mr Green's standard discourse patterns with those associated with the use of a CRS, an intervention was designed. The CRS used in this study was a Personal Response System (PRS) purchased in 2002.[4] The model is a one-way IR system that supports user 'voting' via a button-push on a transmitter (also referred to as a 'clicker') and data collection and aggregation via a receiver and computer interface (Burnstein and Lederman 2001, 2003).

The intervention involved the introduction of the CRS. As Mr Green's standard practice included the regular use of multiple-choice and matching questions for the purposes of review, as homework assignments as well as during tests, the research team and teacher jointly selected multiple-choice questions for CRS use from a set he had previously used for the unit. These questions ranged from simple recall prompts that test whether students had, for example, successfully memorized vocabulary, to application prompts, which require students to recognize how a concept fits with a particular situation. Application prompts provide students with opportunities to apply their forming understanding to a concrete situation, such as how a parallel circuit differs from one in series (see Bloom (1956) for a discussion on question types).

For the CRS activities, students were paired according to their first language, resulting in three pairs of Spanish speakers, one pair of Farsi speakers and two pairs of mixed language speakers. Pairs of students shared one CRS transmitter and were instructed to agree on the correct response. On making their decision, learner pairs 'clicked in' their preferred response to a computer that tallied and displayed responses graphically in the form of a

histogram. Using this histogram, the whole class was invited to discuss relative merits of different answer options, before the teacher confirmed the correct answer.

The configuration of pairs of speakers, ideally with the same first language, and the use of a single clicker by pair, was designed with the express intention of increasing the likelihood of interaction between students with the science concepts and associated English language vocabulary and structures under consideration.

Data sources

Data were collected during a six-day unit on electricity and magnetism in May 2006. Data for this paper were drawn from the three days that considered electricity. The CRS was used on two of the three days. Prior to the unit, researchers observed and took field notes on standard practice in the classroom during the previous week. In addition, prior to the start of the unit, students were introduced to the CRS and had the opportunity to use it to answer a series of entertaining questions, for example about the condition of Mr Green's hair.

The primary data presented here stem from audio- and video-recordings of the classroom sessions. A stationary video camera focused on the room as a whole and six digital voice-recorders, one positioned by each student pair, captured small-group discourse. Researchers' field notes supplemented these data. One week after the unit, a debriefing focused on attitudes about the use of the CRS. The debriefing took the form of a whole-group CRS-mediated discussion around 10 multiple-choice questions, followed by two focus groups, one conducted in Spanish and one in English.

Data analysis

Transcripts of all class periods were prepared and analyzed in a series of iterative cycles, following the analytic framework outlined by Mortimer and Scott (2003). Although classroom activities consist of organizational, procedural and scientific components, only science talk is considered here. An initial transcript of each class session was prepared, focusing on whole class interaction and the interactions in two small groups.

The first step in the analysis was to identify teaching purpose. Our analysis of teaching purpose sought to answer the following question: 'What purpose(s) is served, with regard to the science being taught, by this phase of the lesson?' (Mortimer and Scott 2003, 26).[5] We coded the transcripts using Mortimer and Scott's six purposes: (1) opening up the problem (OP); (2) exploring and working on students' views (EX); (3) introducing and developing the scientific story (IS); (4) guiding students to work with scientific ideas and supporting internationalization (GSW); (5) guiding students to apply, and expand on the use of, the scientific view, and handing over responsibility for its use (AP); and (6) maintaining the development of the scientific story (SS). Two researchers independently coded transcripts for teaching purposes (Cohen's Kappa for inter-rater reliability is 0.81), and then calculated the amount of time the teacher spent on the different purposes throughout the unit.

To determine *access to* and *participation in* discourse, distribution of teacher and student talk in different classroom configurations or *participant structures* was examined. We define access as the way the classroom interaction is structured to allow and encourage students to participate, both through small-group interactions as well as through sequencing of small- and whole-group interactions, which provide students with 'practice' speaking in the small group, prior to whole-group discussions. Transcripts were coded for three types of participant structure: (1) teacher-led whole group, (2) student pair or small-group

interactions and (3) individual student work. A detailed timeline marking teaching purpose cross-referenced with participant structure allowed us to examine comparable segments of discourse with and without use of the CRS. We further tallied the number of participants contributing to interaction, number of turns at talk and the length of turns within the different participant structures.

Finally, we examined the communicative approach (interactive/noninteractive, authoritative/dialogic) reflected in the discourse patterns (IRE versus IRFRF) taking place in the classroom, cross-referenced with the teaching purpose.

Findings

We begin our analysis with an outline of Mr Green's teaching purposes. Table 1 shows the amount of time dedicated to each teaching purpose in three 50-minute class periods. Only four of the six teaching purposes were addressed during the unit; the primary teaching purpose was exploring and working on ideas, with close to 60 percent of the time dedicated to this purpose, followed by introducing and developing the science story. Notable is the relatively small amount of time spent on guiding students to the science story, regardless of whether the CRS was used or not. As discussed above, this type of distribution of teaching purposes is far from rare, and may be a particular characteristic of sheltered English classrooms.

Shifts in participant structure and teaching purpose

Table 2 presents the shifts between whole- and small-group configurations for the same three days and further differentiates non-CRS and CRS-supported segments.

Although Mr Green routinely organized his class with whole- and small-group activities, the rhythm and distribution changed dramatically with the use of the CRS. On non-CRS days, Mr Green tended to engage the whole group in demonstrations and discussions (on average lasting for 11 minutes per segment) followed by individual or small-group work on conceptual explorations with realia, reading, or filling out worksheets. These small-group activities tended to be long in duration (roughly five to 25 minutes per segment), and consisted of interactions between Mr Green and pairs of students during which Mr Green also responded to requests for help from other students. These frequent interruptions resulted in a high degree of off-topic socializing while students waited for the teacher's attention.

With the use of the CRS, the rhythm of talk took more rapid shifts between small- and whole-group interactions. Mr Green's impression of the CRS use was that he was able to assess the extent to which all students had grasped concepts more effectively:

> [Use of the CRS] was good instead of going around individually and seeing while they were working on stuff together. I could know overall as a group whether they got a concept or not. . . . And it seemed like the discussion that was going on was usually pretty relevant to what was going on and it looked like there were some light bulbs going off and a little more communication, which I liked. (25 May 2006)

Mr Green highlights the connection he sees between CRS use and two aspects he considers to be important: (1) his ability to rapidly assess his students' science knowledge; and (2) increased communication relevant to science learning, which in turn might reflect more understanding of the concepts.

More rapid shifts in participant structures alone do not indicate any improvement on the learner's ownership of the meaning-making process or depth of understanding. Figure 1

Table 1. Teaching purpose by time spent (in minutes) per 50-minute class.

Date	Science-related talk (min)	Opening up the problem (OP)	Exploring and working on ideas (EX)	Introducing and developing science story (IS)	Guiding students to work with scientific ideas (GSW)	Guiding students to apply scientific view (AP)	Maintaining the science story (SS)
8 May 2006	32:42	5:18	18:34	5:28	3:22	0	0
9 May 2006	44:59	0:52	29:33	12:07	2:34	0	0
10 May 2006	42:07	0	30:03	10:10	1:54	0	0
Total	119:48	6:10	78:10	27:45	7:50	0	0

Table 2. Shifts in participant structure with and without the classroom response system (CRS).

Date	WG 1 (min)	SG 1 (min)	WG 2 (min)	SG 2 (min)	WG 3 (min)	SG 3 (min)	WG 4 (min)	SG 4 (min)	WG 5 (min)	SG 5 (min)
8 May	12.23	4.29	17.04	13.39						
9 May	4.52*	**2.47**	**2.25**	**3.16**	**4.58**	**3.03**	7.54	17.07		
10 May	**0.52**	**1.57**	**0.34**	**3.15**	**4.51**	**3.42**	**2.03**	**3.43**	7.11	16.07

Note: The bolded sections of the table indicate CRS activities; * the final 23 seconds of this segment were part of the CRS.

provides an example of 10-minute segments of non-CRS (8 May 2006) and CRS interaction (10 May 2006) coded for participant structure and teaching purposes. The segments are roughly comparable as each focuses on a single conceptual idea. The 8 May 2006 segment consists of 10 minutes that include the first small-group segment (4:29) in Table 2; the 10 May 2006 segment overlays with the first 10 minutes represented in Table 2.

Corresponding to shifts in participation structure, CRS use led to a different organization of teaching purposes across participant structures. On the non-CRS segment presented in Figure 1, the teacher introduces a variety of teaching purposes ranging from opening up a problem (OP) to exploring and working on students' views (EX), as well as guiding students to work with scientific meanings (GSW) for about five minutes. A small-group segment of roughly four and half minutes dedicated to exploring and working on ideas (EX) follows. However, when the whole group reconvenes, there is no follow-up or elaboration to the small-group work; rather the teacher moves to opening a new problem (OP). In contrast, in the CRS segment, the initial whole-group interaction is relatively brief (about a minute) and consists of only one teaching purpose, exploring ideas (EX). This is followed by two cycles of small-group explorations (EX) alternating with whole-group introduction and development of the scientific story (IS). After these two alternating cycles, the teacher shifts to the purpose of guiding students to work with scientific meanings (GSW) – as a culminating type of teaching purpose. Figure 1 shows that the CRS-supported segment outlines a more cyclical trajectory of teaching purposes across participant structures.

Shifts in distribution of talk

Shifts in participant structure and teaching purpose coincided with a marked increase in student participation. Table 3 presents data from comparable time segments of whole-group talk spent exploring and working on ideas for the same two days. The examples presented below[6] closely mirror the percent distribution of talk on these days.

During whole-group interaction on 8 May 2006, a non-CRS day, the teacher takes up 95.6 percent of the talk counted in number of words, and one-third of the turns at talk. Student responses are typically one-word responses (average 1.45), while the teacher's turns are long (averaging 63.96 words/turn). This is fairly characteristic of a typical, minimally interactive teacher-fronted classroom style characterized by the IRE format.

Table 3. Comparison of distribution of talk.

Date	Segment length (min)	Number of students	Total words	Teacher words	Student words	Total turns	Teacher turns	Student turns	Teacher's average words/turn	Students' average words/turn
8 May (non-CRS)	11:02	5	1606	1535 (95.6%)	71 (4.4 %)	73	24	49	63.96	1.45
10 May (CRS)	13:03	9	1293	807 (62.4%)	486 (37.6%)	177	63	114	12.81	4.26

8 May		
Duration	Participant structure	Teaching purpose
0:00:22	Whole	OP
0:00:29	Whole	EX
0:00:57	Whole	GSW
0:03:03	Whole	EX
0:04:29	***Small***	*EX*
0:00:43	Whole	OP
0:10:03	Time segment	

10 May		
Duration	Participant structure	Teaching purpose
0:00:52	Whole	EX
0:01:57	*Small*	*EX*
0:00:34	Whole	IS
0:03:15	*Small*	*EX*
0:01:57	Whole	IS
0:00:14	N/A	EX
0:01:06	Whole	GSW
0:09:55	Time segment	

Teaching purpose codes:

OP: Opening up the problem.
EX: Exploring and working on students' views.
IS: Introducing and developing the scientific story.
GSW: Guiding students to work with scientific meanings.

Figure 1. Comparison of participant structure and teaching purpose for roughly 10-minute intervals on two class days; 8 May 2006 did not include CRS use, whereas 10 May 2006 included the CRS.

On 10 May 2006, with CRS use, while the proportion of teacher turns remains roughly the same (a third), there is a decrease in the proportion of teacher's words, from 95.6 to 62.4 percent, with a corresponding increase in the students' words from 4.4 to 37.6 percent. The average words per turn for students increased from 1.44 to 4.26 at the same time that the

teacher's average words per turn decreased from 63.96 to 12.81, suggesting a somewhat more balanced interaction – albeit still with short student responses. Further, the number of student participants in whole-group interactions increases from five to nine students out of 12.

These results suggest the possibility of more interactive discourse patterns, and open the question of whether a more dialogic discourse pattern may be present when students and teachers are exploring and working on ideas prompted by the format of the CRS intervention.

Shifts in interactive and dialogic interaction

To compare whole-group interactions in non-CRS and CRS contexts with respect to the nature of students' contributions to the construction of knowledge, we examine in detail two whole-group interactions that are most characteristic of the CRS and non-CRS interactions represented in Figure 1 and Table 3. To provide context for the interaction in the CRS whole group (Example 3), as well as to examine how science teaching and learning is instantiated by teachers and students, we provide an example of one small-group interaction that immediately preceded it (Example 2)[7]. While one might expect that the amount of time spent on introducing topics as opposed to building on them (as reflected in Figure 1 and Table 3) would shift from the first to later days of a unit, our experience observing this teacher across several units, as well as comparing CRS and non-CRS use at various points within the units, leads us to contend that the differences in the overall organization of the interaction presented here are directly tied to the use of the CRS.

Example 1 presents a characteristic non-CRS exchange with three parts: the teacher's set-up of the problem (lines 1–11), a student's participation (lines 12–22) and a closing with the teacher's explanation (lines 23–32). In lines 1–3, Mr Green outlines the upcoming activity and reminds students of the concept under consideration, i.e. the flow of electrons. In line 4, he poses the problem to be worked on, 'how is it a flow?' and follows with a succession of utterances (lines 5–11) in which he rephrases the same question in four different ways (lines 5–6, 7, 10 and 11), in a type of think-aloud. A prompt to access prior knowledge (lines 8–9) is followed in lines 10–11 by reframing the initial question as a concrete problem (why does it not work?) rather than an abstract problem (how is it a flow?). Line 11 constitutes the first initiation of an IRE sequence.

In line 12, a student, Singh, provides a response (R), pointing out that two opposite poles are necessary, arguably hinting at the need for a closed circuit. The teacher validates the response by repeating the student's words (line 13) and providing an evaluation (line 14), thus closing an IRE sequence. Mr Green fails to take up the student's contribution and thus entertain a dialogic exchange; rather, he begins a new IRE, asking 'what do you need here?' (line 15) and hinting at what he is looking for, 'think about what *this word* means' (line 16) to focus the students on the concept of *flow*. The student's response in line 17, 'electrons' can be interpreted either as a conceptual response indicating *what* must flow or, as is the teacher's interpretation based on his response in line 18, a guess of another individual vocabulary item. In lines 19–20, Mr Green emphasizes the term he introduced initially (*flow*) and poses another question, 'can electrons go anywhere right here?' (line 21), while pointing to a drawing of an open circuit on the board. The same student, Singh, responds with 'No I doubt it' (line 22):

Example 1: The flow of electrons (8 May 2006)

1. Teacher: OK. OK, guys, we're gonna talk about a few different things.
2. We're gonna look at a PPT before we do our reading.
3. We've learned here that electricity is gonna be a flow of electrons.
4. How is it a flow?
5. What did you have to do to make the electrons actually not go to one
6. place and stop, but go all the way around?
7. What did you have to do?
8. (Be)cause sometimes we did this, we had the battery, we had the wire,
9. and we had a light bulb.
10. Why does that not work?
11. It does not work, why not?
12. Singh: It needed the two, positive and negative.
13. Teacher: You needed positive and negative.
14. OK. That's true.
15. What do you need here?
16. Think about what this word means.
17. Singh: Electrons
18. Teacher: No, not electrons.
19. This word FLOW here.
20. The flow of electrons.
21. Can electrons go anywhere right here?
22. Singh: No, I doubt it.
23. Teacher: They need to go around, right?
24. So, they need to go all the way around to the other side and
25. what we have then is electrons go this way, this way, this way, through the bulb
26. and then back into the battery.
27. All the way around.
28. And this is going to be called, you guys with me?
29. It's gonna be called a circuit.
30. It's a path for the electrical current, right?
31. If it's broken, no light's gonna go on.
32. If it's closed, the electrons will flow.

Mr Green takes on the burden of talk and meaning-making process in the remainder of this segment (lines 23–32). He provides a 'visual' description of a closed circuit, makes the connection between a closed circuit and 'flow of electrons', introduces a new term 'circuit' and summarizes the point that only a closed circuit will allow for a flow of electrons. This extract as a whole shows Mr Green engaged in an authoritative, largely noninteractive communication pattern. Even though one student participates, Mr Green does not draw out or build on the student's nascent explanations. In the final segment, the teacher shifts to a noninteractive format in which he introduces part of the science story.

In contrast, CRS use led to substantial interaction including opportunities for students' explicit reasoning. Examples 2 and 3 together outline the process of the initial small-group interaction and the subsequent whole-group exchange related to question 15 on the behavior of bulbs in a parallel circuit. In this way, the purpose of the question and interaction matches that of the discussion outlined in Example 1.

Question 15 consisted of a photograph and drawing of a parallel circuit with three bulbs; two are lit and one is not lit, due to an open branch on the circuit. The accompanying text has stated this:

All bulbs are equivalent and new, and the battery is new as well. What happens when you close the third switch?

1. The two bulbs that are already on will both get dimmer.
2. The two bulbs that are already on will both get brighter.
3. The two bulbs that are already on will not change brightness.
4. There is no way of telling what will happen.

In Example 2, one Spanish-speaking pair, Pedro and Ana, consider the correct answer prior to submitting their answer. Following the teacher's reading of the question to the whole class, they jointly read the question and discuss both the science concept and the appropriate expression of this concept in English. After spending some time discussing the meaning of the word *dimmer*, and reading the question and answer option one, Pedro and Ana focus on determining which of the answer options best reflects their understanding of the answer to the science question, namely that the bulbs that are already on will not change in brightness. Here, two critical aspects emerge: (1) Ana and Pedro establish that they know the answer to the question, i.e. understand conceptually how parallel circuits regulate the flow of electrons, and (2) they are unsure how to choose an English wording that matches this understanding. From this example it is clear that the science question is in fact a language question for Ana and Pedro:

Example 2: Ana and Pedro's CRS exchange (10 May 2006)

1. <u>Pedro: So is the</u>
2. Ana: So, the bulbs that already, ## the bulbs that ## not change
3. *aqui estoy entre este quince xx cual es la que dice major pero*
   %tra: here it is fifteen, which one is the one that says it better?
4. Pedro: xxx
5. Ana: *ocea el xx ya es la respuesta*?
   %tra: so xx is the answer?
6. *Esto no le pasa nada*,
   %tra: Nothing happens to this one,
7. *pero no se cual lo dice, esa o esta, esto que sigue /brillando/*
   %tra: but I don't know which one says it, that one or this one, does it stay bright.
8. Pedro: /*es la dos*/ *si*
   %tra: It's number two, yes.
9. Ana: *pero xxx y esto no cambio su su*
   %tra: but xx and this did not change its
10. Pedro: *no ira aqui dice*, /the two bulbs/
    %tra: no look it says
11. Ana: /*aqui dice que no cambia*/ *su intensidad*
    %tra: its says the intensity doesn't change.
12. Pedro: *no ocea, queda igual*
    %tra: No it stays the same.
13. Ana: *xxx pero la tres dice que no cambia*
    %tra: but three says it doesn't change.
14. Pedro: The two bulbs that already # no change,
15. *ocea no va a cambiar, que no va aver cambio, si quita esto*
    %tra: It's not going to change, there's not going to be any change,
    if you take away this.
16. Ana: *ya pos la tres entonce ## es como mas especifica ah! Sera*?
    %tra: Ok so three then ## its more specific, is it?

Prompted by Pedro's opening, Ana outlines her response 'the bulbs that ## not change' (line 2). Then Ana switches to Spanish to consider how to match her understanding of the science concept to English language structures, as evidenced in line 3 ('which one is the one that says it better?') and again in lines 6–7 where she reiterates, 'Nothing happens to this one, but I don't know which one says it, that one or this one, does it stay bright?'

Having agreed on the scientific concept, Ana and Pedro discuss how to decide between answer options two and three (lines 8–16). They agree that the bulbs in a parallel circuit will not change in intensity when an additional bulb is added on another branch of the circuit, but struggle to interpret the difference in meaning between 'brighter' in answer option two, and 'not change brightness' in answer option three. Ultimately, they decide that answer option three is 'more specific' (line 16) and therefore likely the correct response.

Their struggle hinges on how they interpret the meaning of the verb phrase 'get brighter' with the comparative adjective 'brighter', and the verb phrase 'not change brightness' with the noun 'brightness'. Essentially, they are trying to assign meaning to English at the word or lexical level, rather than at the clause or syntactic level. In their predominantly Spanish negotiation, we see that they are able to explain correctly how a simple parallel circuit operates, although the teacher and any standardized assessment would not be able to see this meaning-making as it takes place in Spanish. The intended science-learning task becomes a *de facto* language-learning task. The students are ultimately able to accomplish the language task and the related science task – i.e. find the correct answer – albeit without a clear understanding of linguistic distinctions presented in the answer choices.

Example 3 presents the teacher-led whole-class discussion after all student pairs had 'clicked in' their selections. Of the six pairs, half chose answer option two and the other half chose the third option; exactly the two options Ana and Pedro struggled with in Example 2. In response to the teacher's request (lines 3–4) for an explanation for answer option two, Pedro chimes in after several others and provides an argument for why this option cannot be the correct one, switching the focus from 'getting brighter' to 'sameness' (lines 10–17). In contrast to his explanation in Spanish in Example 2, his English explanation consists of highly contextualized language, accompanied with pointing to places on a diagram in question 15, saying, 'this is open, this is turn around' (line 15) and 'and this is the same' (line 17). In English, he is unable to offer a clear explanation employing the vocabulary related to intensity of light (e.g. dimness, brightness), which he has outlined in the small-group interaction. In line 18, the teacher restates Pedro's explanation in the form of the question, then accepts and positively evaluates it in a brief exchange with Ana, thereby closing part one of the discussion (line 21). Notable here is the shift from IRE to a series of response and feedback exchanges with several student participants in addition to the teacher providing feedback and evaluation.

Example 3: Whole-class discussion (10 May 2006)

1. <u>Teacher: About half chose number two and about half chose number three. #</u>
2. number two says the two bulbs that are already on will both get brighter.
3. Can someone say why you thought that might happen,
4. if you add one more bulb in parallel, why they might get brighter?
5. Ana: No.
6. Student: More, more light.
7. Pedro: /No!/
8. Ana: /no!/ *esta bien! esta bien!* (%tra: It's right!)
9. Student: more charge. #
10. <u>Pedro: It's the same!!</u>
11. Teacher: It's gonna be the same if it's in parallel?

12. Pedro: Yeah, yes. ######
13. because right here is the picture like
14. Teacher: mhm.
15. Pedro: This is open, this is turn around
16. Teacher: uhhuh.
17. Pedro: And this is the same.
18. Teacher: When you close it you think it'll be the same brightness?
19. Ana: Yes.
20. Teacher: Okay.
21. Ana: *bien*. Xxx
22. Teacher: Number three says the two bulbs that are already on will not change in
23. brightness.
24. Student: yooo.
25. Teacher: Somebody want to try to defend that? How come do you think that?
26. Ahmed: Yes it same.
27. Teacher: Oh you think they'll be all the same brightness?
28. Ahmed: Yeah.
29. Teacher: If you add another light in parallel, same brightness.
30. Ahmed: Yeah.
31. Teacher: What about if you add another?
32. Pedro: The same too!
33. Ahmed: No, always the same, whatever you put, one, two, three, four, five, same.
34. Inves: Why?
35. Pedro: Why?
36. Ahmed: Because is no seria is a p– pr–
37. Tutor: Parallel.
38. Ahmed: Parallel.
39. Inves: Mhm okay.
40. Teacher: Okay, alright.
41. Inves: So the answer is
42. Pedro: Three.
43. Ahmed: Three.
44. Student: Number three.
45. Pedro: Three.
46. Teacher: The two bulbs that are already on will not change in brightness.
47. Student: Yeah (clapping).

Lines 22–40 consist of a joint consideration of answer option three (the correct option). Here, Ahmed and Pedro collaboratively validate this as the correct answer, repeating 'yeah' and 'the same' (lines 26, 28, 30 and 32) as Mr Green repeats the question, each time positing the addition of one more bulb. When one of the researchers intervenes asking 'why' (line 34), Ahmed contrasts the parallel circuit with the series circuit previously studied and then the group collaboratively validates answer option three as correct. Lines 41–47 close the discussion with a restatement of the correct response.

Although the second half of the whole-group discussion does not consist of students reiterating the reasons for the answer in their own words, by this point, in contrast to the whole-group discussion presented in Example 1, students had multiple contexts and opportunities to hear and verbalize the science concept: at least three times in both their native language and in English, in pairs and then twice in the whole-group discussion. This interaction format, through its structured outline of topic and participant structure, generated a type of dialogic interaction in which both science conceptual and language negotiation opportunities took place.

Discussion and conclusion

This case study provides preliminary evidence that the use of technology-supported interventions may result in greater access to and participation in science discourse in English on the part of ELLs in a sheltered English classroom. Notable in this case study is the fact that the use of the technology was new to both teacher and students; nonetheless, its introduction resulted in a dramatic shift in the structuring of the classroom interaction within two class periods.

The CRS-supported intervention opened a space for interaction in a variety of ways. First, the CRS intervention provided a frame for multiple opportunities to engage with the same material, a structure that led to a shift in the distribution and pacing of discourse. CRS-mediated discourse was far more interactive and resulted in students shifting from one-word responses to short contextualized explanations of scientific phenomena in English during whole-group interaction. In a sheltered English class this is significant, as it indicates students making attempts to voice their understandings in English, attempts which the teacher supports through ratifications and repetitions of key terms. Moreover, this is a change over a relatively short time – namely two-class periods.

Second, students both in pairs and later in whole-group interaction had a shared focus of attention on alternative solutions, in the form of different answer options, which opened up a space for students to be cognitively engaged in an analysis of conflicting ideas – the type of interaction which Mortimer and Scott (2003) consider dialogic, albeit in a very preliminary way. However, unlike the goal of science discourse to engage in dialogic inquiry on the science story, the dialogic consideration of options in these data focuses not on developing connections about science but rather on the mapping of knowledge about science onto the English language.

In spite of these positive shifts in the classroom interaction, a number of notable difficulties with science teaching in this classroom became evident as a result of the analysis of the discourse in both the non-CRS and also the CRS-mediated contexts. Over the course of the unit on electricity, no time was spent on two culminating teaching purposes identified by Mortimer and Scott (2003). Rather, as with many classrooms, the focus of learning remained on relatively disconnected explorations of scientific ideas.

Further, although the amount of student science talk clearly increased, their contributions remained short and often highly tied to the contextual clues available in the form of visuals in the classroom in order for their meanings to be understood. Even with the task of exploring ideas about science in English, students demonstrated a lack of ability to use linguistic resources to express their science knowledge. Example 2, an in-depth consideration of how students interacted in small groups, provides evidence that everyday vocabulary items may be challenging to ELLs. Here, students had difficulties with everyday terms and phrases (i.e. get brighter, same brightness). Teachers often assume English learners know such nonscientific vocabulary; yet lack of such knowledge draws students' attention away from science and may prevent them from expressing the knowledge they have in English. Moreover, such difficulties transform the focus from building science knowledge to building language capacity.

A number of studies report that dialogic inquiry is rare in science classes (Kelly 2007; Mortimer and Scott 2003) and even more so in science classrooms with ELLs (Haneda and Wells 2008; Langman and Bayley 2007). Haneda and Wells (2008) further suggest that instances of sustained dialogic inquiry among ELLs tend to be found only with teachers involved in sustained action research with researchers. Given these findings, the potential for technology-infused interventions, such as that reported here, which show the possibility of disrupting a teacher's standard interactional practice in favor of one that creates more

space for interaction in a very short time is promising. With more carefully designed interventions and teacher training focusing on how to guide students in greater explorations of science content, more interactive and more dialogic discourse patterns may be possible.

We conclude with a set of implications derived from reflections on the nature of the intervention, in particular the questions used to prompt interaction, and the ways in which the students conceptualized the tasks in a context where science content is language content (Lee and Luykx 2007).

Implications

This study extends the CRS literature finding that the tool has the potential to increase engagement – based on the number of students participating and the average number of words per speaking turn – in classrooms to a new group, namely ELLs in a high school sheltered science classroom. In this study, the tool's primary functions were to pace the classroom discourse, provide opportunities for peer learning and create a shared space for considering science concepts. The CRS intervention shifted the rhythm of discourse toward a more learner-centered framework of participation with alternating small- and whole-group segments, increasing students' *access* to and *participation* in the discourse. Such multiple opportunities for content-rich student–student and student–teacher interactions are particularly important for ELLs who struggle simultaneously with meaning-making of content and language.

Careful contemplation of language use and language tasks in conjunction with science is important in the construction of materials for use with the CRS as well as in general classroom activities. From the discourse analysis of activities enacted through language (Gee 2005), we see a distinction between how the teacher conceptualized the activity in Example 3 as one of building science knowledge and the students' articulation of activities as English language learning. Highlighting such differences in understanding based on language as opposed to science concepts can provide a starting point for teachers and teacher educators to address challenges science teachers face when working with ELLs.

Although this study did not center on the efficacy of particular questions, a note is warranted relative to the impact of questions on dialogic engagement, regardless of CRS use. The questions in this study intentionally resembled multiple-choice questions as they are frequently used in textbook chapters, examinations, state assessments and further aligned with the pre-existing classroom structure. The discussion of question 15 above highlights how development should take both content and language into consideration. Questions that are either beyond the scope of students' understanding of either the science involved or the English vocabulary or are too easy will not result in productive dialogic engagement. Questions with a level of difficulty within the learners' reach, but with solutions that are not yet quite obvious, fall within what Vygotsky (1986) termed the Zone of Proximal Development (ZPD) and serve as points of departure for rich explorations of content and linguistic meaning. Beatty et al. (2006) and the 'peer learning' concept (Mazur 1997) outline effective question design and implementation in combination with a CRS as one involving a 'question cycle' tied to increasing elaboration of the science story. This study further highlights the need to consider both language and content components of those questions in the design sequence.

Beyond the quality of the question and the use of the CRS tool, we reiterate the importance of considering the entire pedagogical framework when evaluating the effectiveness of educational technology. A CRS can be added to any type of pre-existing classroom

format and pedagogical orientation. In this study, students worked and made selections in pairs. They needed to negotiate with each other regarding which answer option was most representative of what they thought the correct response was, engaging in meaning-making of both the science content and the academic language relative to it. These small-group discussions were followed by a whole-group discussion segment, resulting in iterative cycles of meaning-making opportunities, in both their L1 and English. Hence, our focus here is not the tool itself, but rather on how a simple technology tool, embedded in an interactive lesson plan, may be used to support shifts to more productive classroom interactions that draw a range of learners into the meaning-making process in a relatively short time period. With more sustained training and better integration of questions into a question cycle that supports more in-depth teaching purposes, such simple tools may provide frames for improvements in science learning among ELLs.

Notes

1. IRE patterns of discourse refer to triadic turn-taking structures in which the teacher asks a question (I), a student provides a response (R), which is followed by teacher evaluation of that response (E). This pattern has been identified as the backbone of traditional classroom interactions (Cazden 1988; Larson and Marsh 2005; Mehan 1979) including the science classroom (Lemke 1990).
2. EAL stands for English as an Additional Language.
3. All names are pseudonyms.
4. For details, see www.interwritelearning.com/products/prs/.
5. Note that this approach aligns with Gee's orientation to discourse (Gee 2005) in which he presents a framework for examining how discourse enacts learning, or, to borrow Gee's metaphor, to examine what tasks are accomplished through discourse.
6. For transcription conventions, see Appendix.
7. Note that we do not provide a detailed analysis of small-group talk on non-CRS days. As outlined above, there was often little direct connection between small- and whole-group interactions on non-CRS days.

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Appendix. Transcription conventions

Transcription conventions are adapted from the CHILDES transcription system (MacWhinney 1991).

Symbol	Meaning
/. . . ./	Overlapping speech
(. . .)	Comment on action accompanying talk
Italics	Spanish
(%tra: xxx)	Translation of Spanish text
. . .	Missing text
#	Pause of approximately one second
Xxx	Unintelligible speech
[]	Phonetic representation
Underlining	Turning points in the discourse